Lifetime and Degradation Science of PERC Technology: Simultaneous optimization of lifetime, efficiency, cost

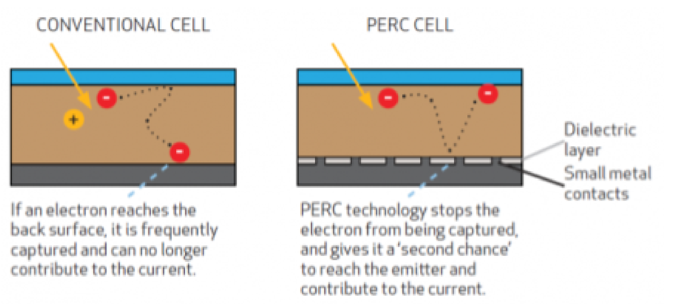
Jennifer L. Braid[1], Joe Scardera[2], Hongping Zhao[1], Bryan D. Huey[3], Roger H. French[1]

1. Case Western Reserve University
2. DuPont Photovoltaic Solutions
3. University of Connecticut

SDLE

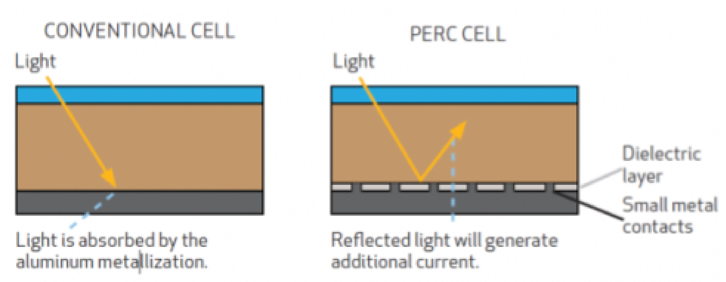
SOLAR DURABILITY AND LIFETIME EXTENSION CENTER

PERC Cells & Degradation



PERC-specific concerns:
1. stability of Al_2O_3 passivation
2. formation of voids at the local Al back contacts, increasing current crowding which potentially raises the operating temperature
3. high sensitivity to light induced degradation (LID), since the bulk carrier lifetime (τ_b) limits recombination.

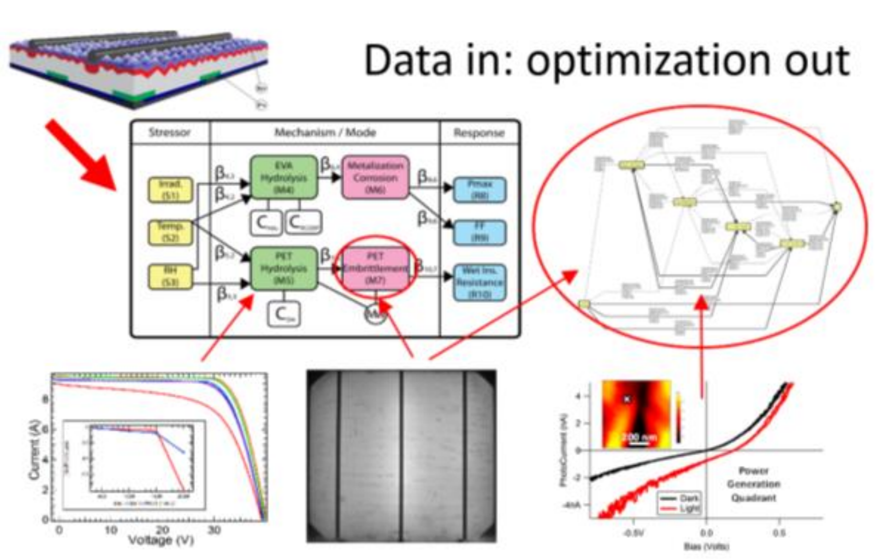
PERC (passivated emitter rear cell) solar cell technology is an upgrade from standard AL-BSF solar cells which increases efficiency by using an aluminium oxide (AlOx) passivation layer to improve the transformation of solar energy into electric energy.



Technology Summary

We will advance our BAPVC-funded development of **multivariate predictive network modeling of degradation data** by combining with process variables and throughput time to **optimize cost/efficiency/lifetime of PERC cells**. We will utilize sample variants in processing, experiences in conventional solar cells and macroscopic and microscopic semiconductor physics characterization schemes to develop rapid insights into fast lifetime testing, degradation mechanisms vs process conditions, and throughput time in fabrication by partnering with DuPont PV Solutions and The University of Connecticut. Data analytics developing multi-scale network models to indicate the quantitative impact of these variables on the device outcomes and simultaneously optimize while meeting efficiency, CapEx and lifetime goals of 20%, \$0.25/Wa and 40 years, respectively.

Network modeling for predictive degradation



sgSEM network modeling tool predicts lifetime behavior of PV modules using multivariate analytics.

Expansion of this development to incorporate more device physics, material characterization, and process variables so as to optimize cost and lifetime performance using multiscale sgSEM of next generation passivated emitter rear cell (PERC) solar cells.

Project Outline

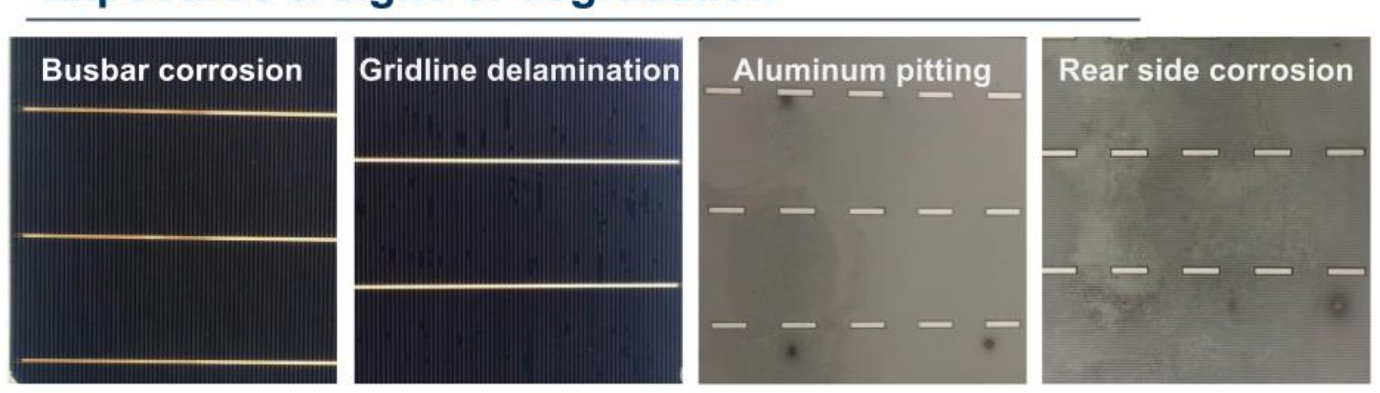
Task1: We will obtain cells and mini-modules from DPVS with varying passivation materials schemes including candidates of an optimized SiOx and variants of AlOx processing, all deposited by PECVD.

Task2: Samples will be characterized by Current-Voltage (I-V), Electroluminescence(EL), Quantum Efficiency(QE), and Photoluminescence(PL) at CWRU, select samples will be sent to UConn and CSM for Atomic Force Microscopy (AFM) and Time-Resolved Photoluminescence (TRPL), admittance spectroscopy, respectively.

Task3: Samples will be exposed to several multifactor accelerated aging conditions and the real world in Cleveland, Ohio on the SDLE Research Center's "SunFarm" instrumented outdoor test facility.

Task4: Repeat the characterization outlined in Task 2 stepwise in time to discern the performance over time. Retained samples will be sent to partners for careful spectroscopic and microscopic characterization. Apply sgSEM methodology to develop quantitative network models from macroscopic to microscopic variables, optimize processing for lifetime performance and efficiency and cost.

Exposures & signs of degradation



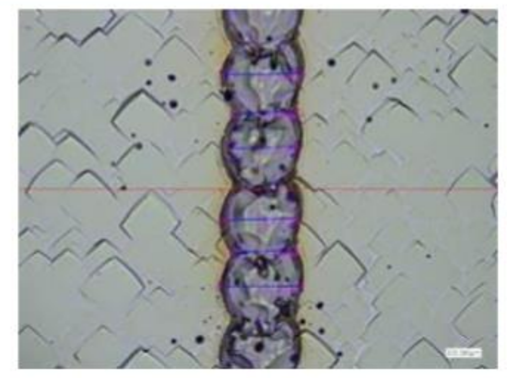
Bare cell exposures:
- Acetic Acid: concentration comparable to degraded module
- Cyclic QUV: alternating heat+UV and condensing humidity

Preliminary bare cell experiments revealed different types of degradation for acetic acid and QUV exposures, depicted above, associated with various power loss modes (series resistance, etc.).

Bare Cell Characterization

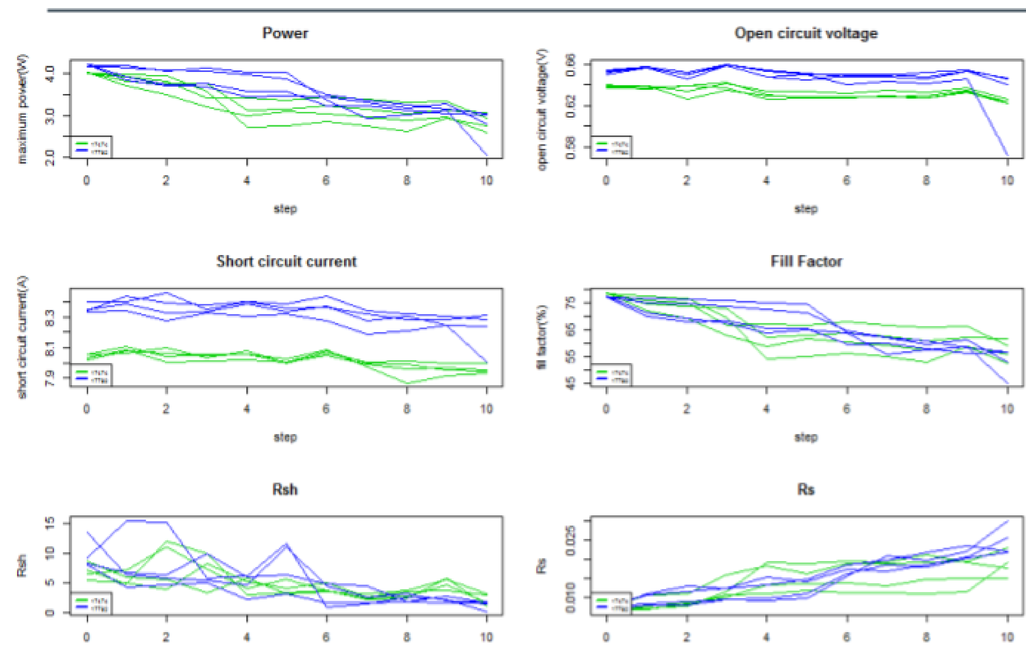
Time-series data over exposure steps including:

- **Current-voltage curve tracing (I-V)**
- **External quantum efficiency (EQE)**
- **Electroluminescence imaging (EL)**
- **Time resolved photoluminescence (TRPL)**
- **Photoconductive atomic force microscopy (pc-AFM)**



Optical microscope image of laser-cut opening in the rear side dielectric stack of a PERC cell before Al printing (DuPont).

Bare cell acetic acid corrosion



2.5 M aqueous acetic acid (concentration in a degraded module)

4 hour exposure steps

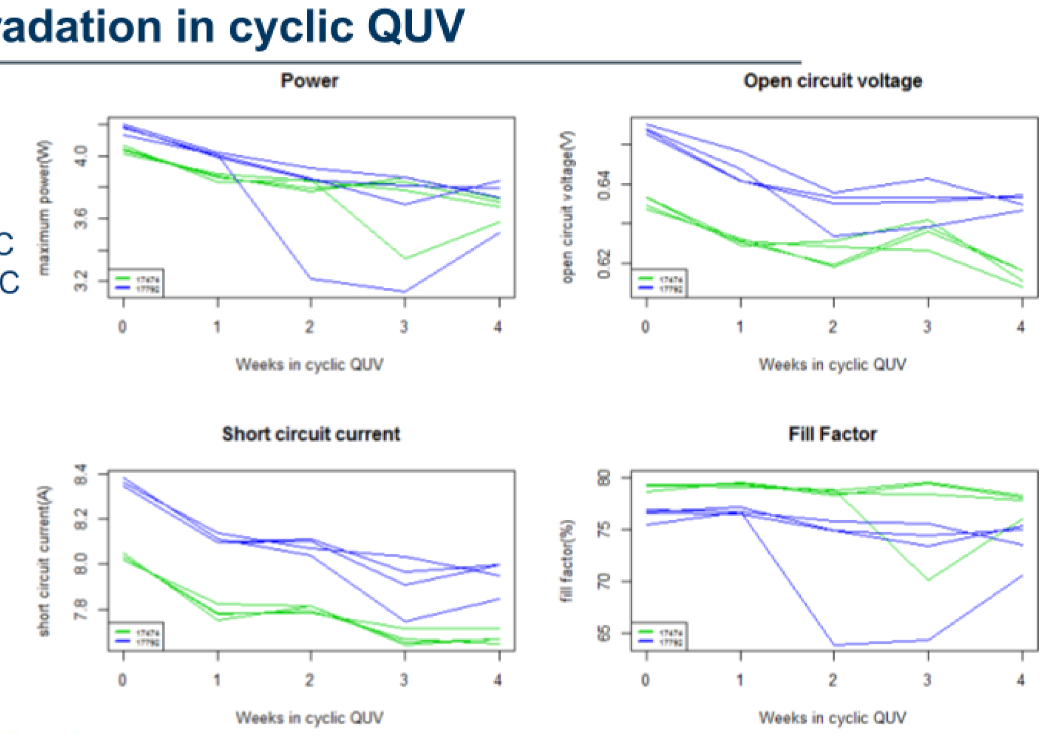
Power decrease tracks with fill factor (increased series resistance), consistent with contact corrosion.

Bare cell degradation in cyclic QUV

ASTM G154 protocol:
- 8 hr 1.5 W/m^2 UV 70° C
- 4 hr condensation 50° C

1 week exposure steps

Power loss tracks with open circuit voltage and short circuit current, consistent with LID.



Mini-module Design

Bare cells and mini-modules of types:
- Al-BSF
- Al_2O_3-PERC

Mini-module design allows for stepwise testing of individual cells as well as full module tracing during exposure

Mini-module exposures:
Outdoor, DH+Light Multi-Factor

Mini-module Characterization

***In-situ* mini-module level current-voltage curve tracing (I-V)**

Stepwise cell level current-voltage curve tracing

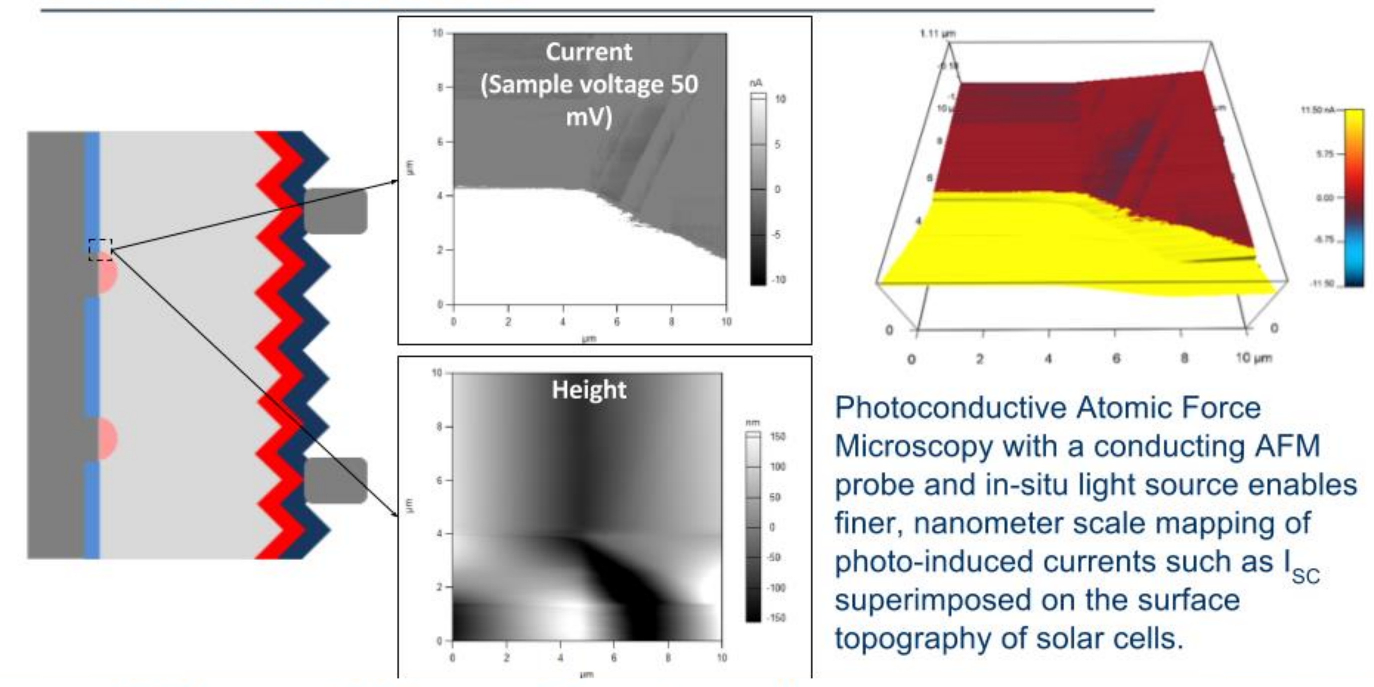
Capacitance-voltage profiling (C-V)

Deep level transient spectroscopy (DLTS) - expanded to mini-modules

Electroluminescence imaging (EL)

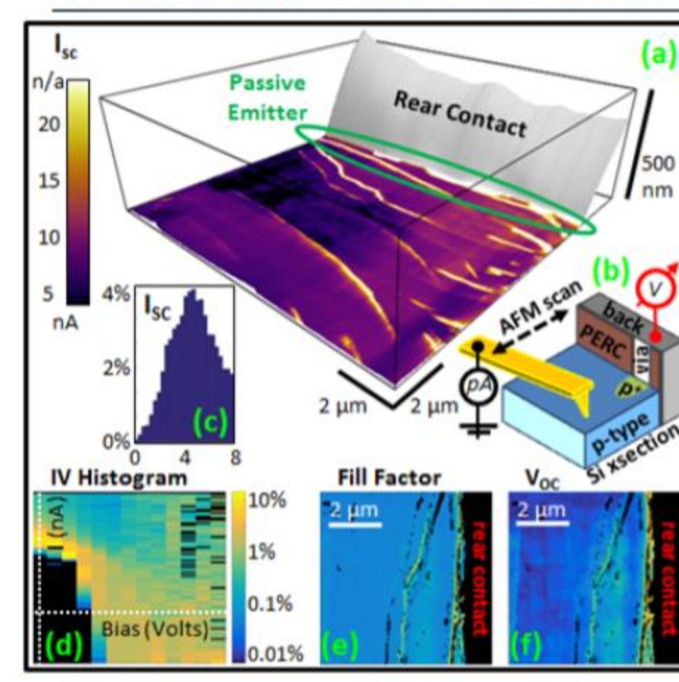
Photoconductive atomic force microscopy (pc-AFM)

Photoconductive AFM



Photoconductive Atomic Force Microscopy with a conducting AFM probe and in-situ light source enables finer, nanometer scale mapping of photo-induced currents such as I_{SC} superimposed on the surface topography of solar cells.

pcAFM capabilities on Si solar cells



Full-field images, with resolution to 1 pA and 10 nm

(a) 3-D map of I_{SC} superimposed on the topography at the Si/rear-contact interface for a cross- sectioned PERC solar cell

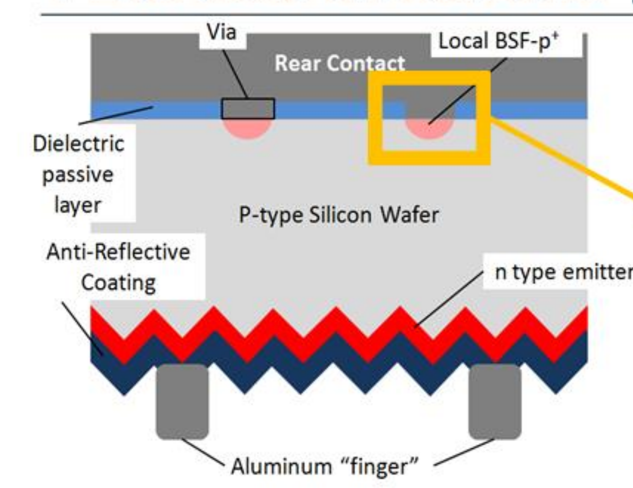
(b) proposed experimental schematic

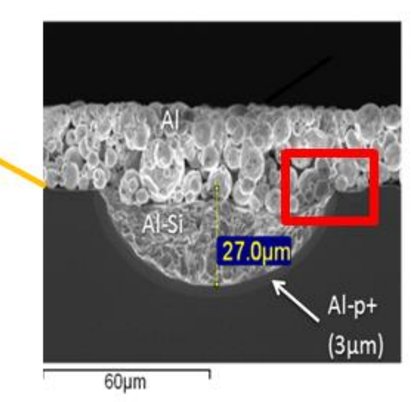
(c) example of resulting I_{SC} histogram from 1 image

(d) 2-D histogram of local I-V spectroscopy throughout the power generation quadrant

(e) and (f) maps of the correspondingly calculated fill factor and V_{OC}, respectively.

PERC areas of interest for pcAFM





Triple point – intersection between BSF, aluminum contact, and silicon

Targeting the p-doped Si bulk absorber, the passivated emitter at the rear contact, and the p+ doped via connecting directly to the back electrode to inspect for evidence of light-induced degradation, as well as formation of voids at the local Al contacts.

Technology Impact

CapEx reduction will be primarily achieved in this program through achieving high throughput, while maintaining lifetime targets. There are dependencies among our three critical design parameters: **CapEx and material costs, efficiency, and lifetime**; that typically are not simultaneously optimized. Here we will meet an aggressive timescale by using **multivariate big data analytics** combined with **semiconductor device physics** to simultaneously optimize CapEx, efficiency and Lifetime. CapEx for cell, wafer and module of typical cells is ~\$0.55/Wa; multicrystalline PERC at efficiency of 22% and an increase in throughput of 40%, the resulting amortized CapEx would be \$0.25/Wa.

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